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14. ABSTRACT
Distributed Mission Training (DMT) is a revolutionary team-training paradigm currently evolving at the US Department of Defense, especially in the Air Force. The objective of DMT is to concurrently train people in team efforts involving coordination, communication, and decision making. The teams may not necessarily be collocated and could be engaged in independent as well as coordinated tasks at remote sites. The attached papers are a collection of DMT articles written by personnel of the Air Force Research Laboratory's Warfighter Training Research Division, in Mesa AZ, and published in the September 1999 issue of COMMUNICATIONS of the ACM.

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DMT; Distributed Mission Training; Team training; Training; Integrated team training; Shared environments; Real, virtual, and constructive systems; Synthetic training environments; Virtual training platforms; Image generation systems; Roadrunner '98;

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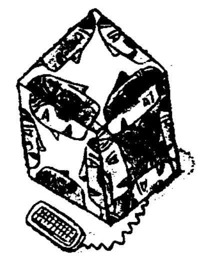
R. Ramesh and Dee H. Andrews,
Guest Editors

DISTRIBUTED MISSION TRAINING TEAMS, VIRTUAL REALITY, and REAL-TIME NETWORKING



Distributed Mission Training (DMT) is a revolutionary team-training paradigm currently evolving at the U.S. Department of Defense, especially in the Air Force. The objective of DMT is to concurrently train people in team efforts involving coordination, communication, and decision making. The teams may not necessarily be co-located and could be engaged in independent as well as coordinated tasks at remote sites.

While the U.S. is pioneering these technologies, several other countries such as U.K., France, Israel, and the Netherlands are also seriously engaged in such initiatives.

The rapid expansions in the dimensions and complexity of contemporary team missions are leading to a tremendous emphasis on the needs for effective, integrated training systems to provide realistic environments for the acquisition of sophisticated and multifaceted team skills. However, such training has yet to come of age. One of the primary reasons is increasing resource limitations such as the availability of actual equipment for training purposes, costs associated with real-world training environments, and safety and security reasons that could forbid mission training in real operating scenarios. This predicament severely restricts the scope of live, integrated team-training possibilities. Also, team efforts could involve several geographically dispersed

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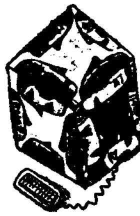

DMT IS STILL VERY MUCH THE STATE-OF-THE-ART. It is expected to become the state-of-practice in the next millennium.

Table 1. Critical DMT research questions.

Behavioral
- How do teams work in real-world missions?
- What makes an individual a solid team player?
- What are the training needs of teams to accomplish their real-world mission objectives?
- How can the virtual, real, and constructive modalities of team training be integrated into an effective human-centric training system capable of delivering fully mission-ready team players?

Technological
- How can integrated training systems be designed? Are their architectural design specifications or industry standards?
- What are the state-of-the-art design challenges and emerging solutions in the various components of integrated training systems such as virtual reality platforms, visual systems, and networking infrastructures?

System Implementation
- How are DMT systems configured in practice?
- What are the modalities of team training in integrated DMT systems and how training scenarios are captured and presented?
- What is the quality of training realizable from DMT systems? What is the extent to which VR-based training could translate to real-world missions performance?

individuals operating from different platforms at remote sites, who need to work together in a coordinated manner to achieve the mission objectives. From a practical standpoint, it could be very difficult, or even impossible, to assemble them in a single place to train together.

These constraints are especially evident in military training programs that require multiple air crews operating diverse units such as aircraft and other weapon systems in different places. They need to train, communicate, coordinate, and work together to achieve common objectives. Until recently, such training was usually conducted in isolated programs at different bases using both the actual equipment and simulated environments. Consequently, the full potential of integrated team training has yet to be realized. In fact, it is somewhat paradoxical that while people are required to operate as integrated teams in real-world situations, the constraints in training do not allow them to practice such missions beforehand and prepare for eventual demands.

The answers to these daunting challenges lie in combining three evolving streams of technology: *VR, remote networking,* and *multimedia (image, data, voice, video) communication*—the backbone of DMT. While many useful VR applications are fast emerging in diverse areas such as medicine, engineering design, scientific visualization, and education, human training is a fundamental area where it is critically needed. Indeed, it has already made a significant impact. Training teams of people to coordinate and work together toward a common objective is a big challenge. VR, coupled with powerful image processing and distributed networking technologies, presents a formidable array of technological solutions to this challenge. DMT is a concept that originated from this perspective, and has evolved into a prototypical technology level that leads to experimentation, analysis, and further development.

DMT is based on three principles: teams—not individuals—execute missions, team skills are built upon—but different from—individual skills, and a combination of the three technology streams could enable creative training opportunities that overcome the limitations of time, distance, and training resources. Consequently, DMT is strongly emerging as an effective mode of team training. A large industrial support base consisting of companies engaged in training methodologies and systems, virtual simulation platforms, networking, and multimedia database systems is rapidly developing. Additionally, these efforts are sparking considerable research on team training and the associated technologies at universities, federal laboratories, and the industrial sector.

Although DMT as a concept has originated from the training needs of the military, it has far-reaching implications to team training in numerous other fields as well. Training commercial pilots, air traffic controllers, navigators, instrumentation specialists, and assembly-line workers all require real-time coordination and communication. The DMT concept

provides a powerful framework to develop integrated virtual, constructive, and real team-training platforms for these applications.

DMT is still very much the state-of-the-art. It is expected to become the state-of-practice in the next millennium. Currently, distributed networks linking several aircraft simulators at each DMT node have been developed and implemented in the U.S. Air Force. They will be deployed, tested, and eventually inducted into their larger training systems. The current DMT trainer web is a secure intranet hosting actual aircraft, and virtual and constructive aircraft simulations and other logistics support. Extensive research and development on DMT systems is an ongoing, high-priority initiative within the U.S. Air Force.

While DMT is a promising technological revolution in the training world, there are also several challenges ahead. Some of the critical questions remaining are: How and when DMT should be used as part of a formal training program involving a multitude of team skills and equipment? What are the technological design options and how should DMT systems be configured? What are the current technological and operational limitations of the DMT technologies, and how can they be overcome? How should DMT systems be developed and implemented in any team training application?

These questions lead to an analysis of the potentials and challenges in DMT from three perspectives: behavioral, technological, and system implementation (see the accompanying table).

In this section, we try to provide some answers to these specific questions. Carroll presents a vision for the emerging DMT landscape and Bell addresses the behavioral questions. Dahmann et al. present an architectural standard for DMT that will soon become an IEEE and NATO standard. Peppler and Stephens address the challenges and emerging solutions in visual imagery in virtual platforms, and Crane presents an analysis of a real-world DMT implementation, practical experience with DMT, and performance assessments from controlled team training studies. **C**

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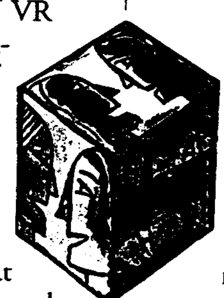
LYNN A. CARROLL

MULTIMODAL INTEGRATED TEAM TRAINING

DISTRIBUTED MISSION TRAINING IS THE CREATION OF A SHARED ENVIRONMENT comprised of real, virtual, and constructive systems that allow teams of individuals to train both individually and collectively. While DMT is primarily a team-training concept that has evolved in the U.S. Department of Defense for its operational forces, its foundations in terms of training principles and technologies have far-reaching implications to the field of human training in general.

The concept of DMT and its potential applications have their roots in the creation of an immersive, fully integrated, seamless information system that connects independent simulation-based training environments to operate together. The result is a synergistic, hybrid environment of VR systems in which information is dynamically shared and used among a group of individuals engaged in real-time mission critical activities requiring coordination and communication. Such a hybrid environment would provide significant economies, compared to the cost of moving people and resources in training at the scale of global operations with actual equipment. This concept is particularly relevant to the training programs in the military, where collective training involving several weapon systems, command and control systems, and training systems is becoming increasingly critical. This training possibility is envisioned through a seamless integration of real, virtual, and constructive domains of operation in a global environment.



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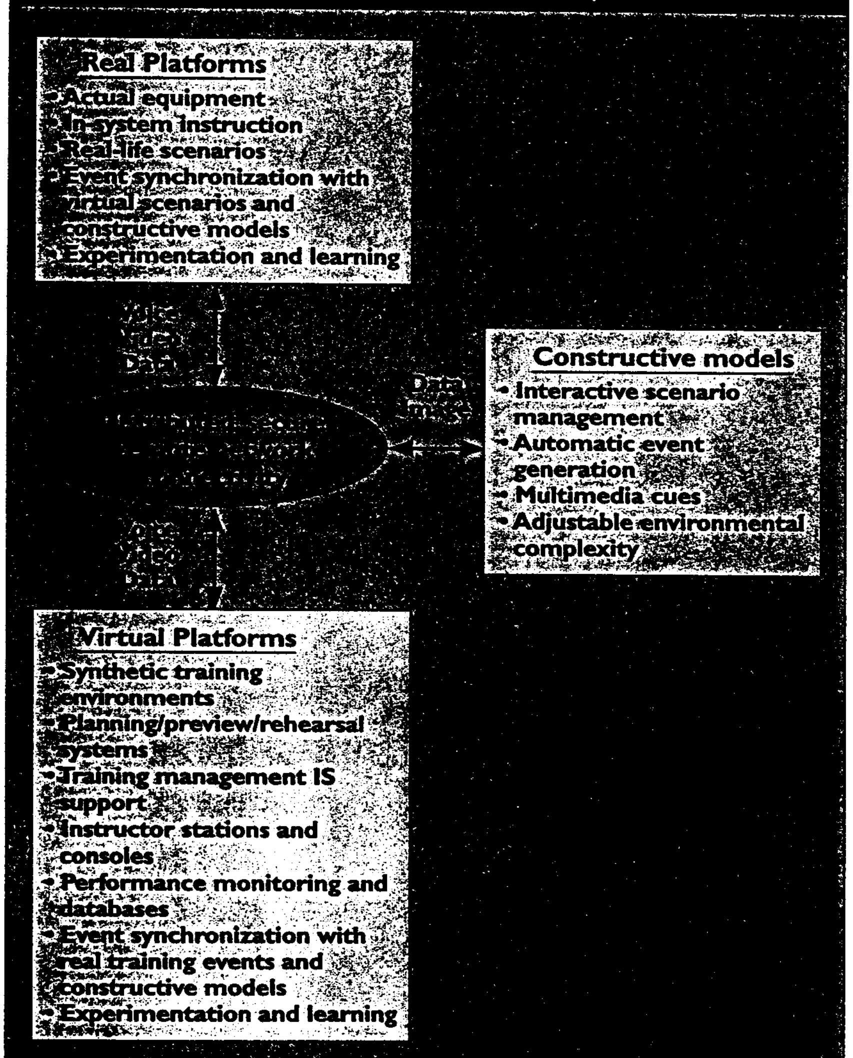
The synergistic combination of the three primary domains of DMT can become both the training and the operational backbone of future enterprises, where actual operations and training events are differentiated only by their objectives and outcomes. The real portion consists of the actual operational equipment; in the military context, this will be weapon systems, command and control systems, information, surveillance, and reconnaissance assets and the logistical support infrastructure. The virtual portion consists of the training environment and

media, such as equipment simulators, synthetic environments, planning/preview/rehearsal systems; training management systems, distributed and secure connectivity, instructor/operator stations, performance measurement systems and archival capabilities. It's clearly obvious these components could constitute a VR training environment in any operational setting. The constructive portion consists of interactive and animated computer-generated models that enrich the training environment by adding desired levels of operational characteristics and complexity. A high-level view of the evolving DMT framework is shown in Figure 1.

Figure 1. A framework for DMT systems.



The training and readiness benefits of DMT will become apparent when these disparate systems are integrated to create an interactive, dynamic environment. This will allow each media to be used independently or synergistically to support all levels of training: individual, procedural, and coordinated team training involving high levels of communication and decision making. In the military context, this can be seen as a real component of DMT consisting of weapon systems to operate in existing airspaces and ranges; a virtual component consisting of simulators conduct training in realistic synthetic renditions of those same areas; constructive computer-driven models will provide the training scenarios at both the real and virtual levels. Real-time networks provide the connectivity for planning and execution of tasks by players at remote locations. Depending on their objectives, the players will then have the option to operate using their respective actual equipment or simulation components to optimize performance and training effectiveness, and minimize operational risks in live training.

Performance and Cost Implications

The underpinnings of these new training environments lie in the potential of affordable and effective computational, network, and simulation technologies. A suite of core training technologies is rendering this possible. Regardless of the application, the focus of the emerging technologies is to provide individual and team access to mission-critical data, accuracy in VR representations of the real world, and coordination mechanisms. With the increasing needs to enhance the quality of communication and decision making in team training, DMT systems are beginning to provide novel capabilities for experimentation and learning. The constructive models of simulation, cue coordination through real-time synchronized imaging systems, and online connectivity for both human and model-level communications have been proven prototypically.

A global training enterprise like DMT could be somewhat expensive. In particular, R&D and procurement represent significant investments. However, the costs for global DMT should not be viewed as totally additive. In fact, if DMT is viewed as a unifying, integrating concept, then significant economies

of scale and scope can result from up-front commitments to universally support its implementation. Note that DMT is viewed as an environment integrating real, virtual, and constructive domains. Therefore, the already committed investments in the real components of existing training systems do not accrue in DMT costs in totality, except for any reengineering and adaptations to these systems that may be necessary for their integration with the DMT environment. In the military context, the existing weapon systems and command and control systems belong to this category. However, DMT requires additional investments in simulators, training platforms, imaging systems and networking capabilities. In fact, DMT can also be viewed as the next generation virtual and constructive training systems by many organizations when the existing facilities come up for upgrades. Consequently, this could also entail a proration and absorption of some of the DMT costs from existing training capabilities.

Furthermore, the core technologies of DMT are nearly universal; they are common to most types of training, education, and even entertainment environments. As a result, multiple benefits in different domains of applications can be derived from any R&D investment in DMT technologies. Reducing dependence on the actual operating equipment for training by using DMT in conjunction will dramatically lower operating costs while extending the lives of the actual operating systems. Synergistic, hybrid environments could also make training more effective. DMT can create a substantial improvement over current capabilities for a modest increase in cost over what is already being committed for disparate activities. In fact, a common global vision for this integrating concept could conceivably lower the cost for a far superior training capability. C

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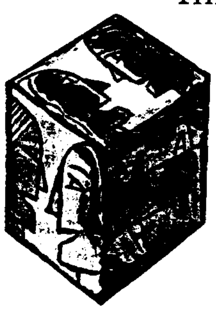
HERBERT H. BELL

THE EFFECTIVENESS OF DISTRIBUTED MISSION TRAINING

Synthetic training environments can enhance teamwork performance.



THE ADVANCES IN COMPUTING AND COMMUNICATION TECHNOLOGIES have led to synthetic training environments with tremendous potential. Distributed Mission Training is such an environment. DMT has adaptively focused and integrated VR and networking technologies for team training in dynamic operational environments. Intra- and interteam communication, coordination, and decision making in such environments are central to mission-critical team performance. While these attributes are especially significant in military operations, they define effective teamwork in general, ranging from sports and entertainment to production and service environments.

The concept of DMT has been technologically demonstrated in defense operations. Equipped with advanced image generation technologies, high-resolution displays, and secure distributed networks, DMT systems connect a wide variety of local and geographically dispersed virtual training platforms for mission-critical team training. Further, DMT technologies provide extremely high levels of both physical and functional fidelity in team training. The resulting real-time virtual training networks include aircraft simulations and other simulated systems such as tanks and ships. In addition, these platforms can be linked to actual training equipment, such as aircraft, thus offering the potential for synthetic environments that support training at the individual, team, and joint service levels. As a result of these increased capabilities, combined with significant reductions in costs, the training and technology development communities are greatly expanding their use of synthetic virtual training environments.

However, there are still formidable challenges in the implementation of these systems. Indeed, training is substantially more than putting hard-

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Table 1. [illegible]xtual factors in [illegible]-world operations
[illegible]
How uncertain and [illegible] are the operational environments?
[illegible]
How do action/feedback loops [illegible] operational strategies?
[illegible]
How high are the stakes in operational decision making?
[illegible]
How do the operational goals conform to organizational norms and objectives?

Table 2. Attributes of effective performers in team contexts.
[illegible]
2. **Speed.** Ability to make rapid decisions, often in the face of severe consequences.
[illegible]
4. **Adaptability.** Ability to recognize when and how to apply an action strategy and when to change or modify the strategy with problem demands.
[illegible]
6. **Accuracy.** Ability to state accurately what is obvious; quick and deep understanding and effective communication.

Table 3. Major skill areas in effective team training.
[illegible]
Situation assessment skills. Make rapid, accurate assessments of situations; cue/pattern recognition and assessment of their significance.
[illegible]
Reasoning skills. Analogical and casual reasoning; creative problem solving.
[illegible]
Mental simulation skills. Know when to simulate a scenario mentally and use it to evaluate strategies for novel problems.
[illegible]
Other psychomotor skills. Specific to a training scenario.

ware and software systems to work together. It involves managing the participants' training experiences to give them a greater potential for accomplishing real-life missions than before. Indeed, training is a systemic phenomenon. The development and implementation of instructional systems [4] follows the general principles of systems engineering in that it involves mission analysis, identification of system inputs and outputs, and allocation of functions to various system components. Based on this concept, simulators are merely subsystems or components of the overall training system. Consequently, it is necessary to ask whether or not these components are functioning correctly and generating the proper outputs. This leads us to the key question in the design and implementation of DMT: Does the integration of DMT technologies into a training system materially improve the likelihood those who use DMT will successfully accomplish their missions?

This article examines this question. In particular, the article focuses on the challenges DMT should address, existing empirical and analytical data that gives cause for optimism, some design considerations for DMT systems, and the major cultural changes that must take place in the way organizations view training so that DMT can have the largest possible impact.

Team Training Poses A Naturalistic Paradigm

A naturalistic perspective on training is to view the process and its effectiveness from the way people use their experience to analyze, interact, and make decisions in field settings [7]. This is dramatically different from the traditional ways of analysis in the sense that emphasis is placed on how trainees are concerned about sizing up a situation and refreshing their situational awareness through feedback, rather than reacting to environmental stimuli and their demands. The contextual factors that affect the way real-world operations occur are central to naturalistic analysis, and are summarized in Table 1.

A central theme emerging from an analysis of training processes is that decision making stems from situational awareness and assessment, prioritization in dynamic task environments, and action/feedback structures in event management. Individuals operating collectively in mission-critical, task-oriented environments are, in essence, decision makers who together determine the final outcome of a mission. So, the naturalistic perspective requires an investigation of what makes them effective decision makers. Once established, these attributes can be used to specify which knowledge, skills, and processes must be learned in order to achieve targeted performance. Table 2 presents a summary of attributes of an effec-

Does the integration of DMT technologies into a training system materially improve the likelihood **THOSE WHO USE DMT WILL SUCCESSFULLY ACCOMPLISH THEIR MISSIONS?**

tive decision maker operating within the context of a team and its goals.

The objective of any team-training enterprise is to develop individuals trained to a desirable level of expertise in these attributes. This translates to a training focus on the major areas shown in Table 3.

This analysis clearly describes what is required to accomplish mission-critical team performance. First, context-specific domain knowledge is crucial. Next, a set of cognitive processes and skills need to be addressed (see Table 3). Finally, the psychomotor skills required in the operational settings need to be emphasized. Focusing on these facets in a training program would accelerate the acquisition of proficiency, and the learning and organizing of domain knowledge that supports complex team maneuvers. These capabilities are crucial in achieving the ultimate objective of a desired level of expertise in both individual tasks and team missions. Team training based on a combination VR technologies and real-time concurrent connectivity among remote players addresses these facets, while at the same time it appears to overcome most of the practical limitations of time and space in a meaningful training environment. While concurrent connectivity is necessary in team-training scenarios, the role of VR as a training medium has been a subject of great discussion among researchers. We take the position that VR is indeed an effective medium given the following line of reasoning.

First, simulated training environments can significantly accelerate proficiency by exposing trainees to the kind of situations they are likely to encounter in the real world, but which could be hazardous or very expensive to practice in actual operational settings. For example, in training Air Force pilots in mission combat, shooting an enemy aircraft can never be practiced with real aircraft exactly as would be encountered in an actual situation. Second, simulations can be controlled—the characteristics of the training scenarios, situational cues, and decision outcomes can be provided as aids in the development of situational awareness, pattern recognition, and template building. The constructive models that play a crucial role in DMT systems are intended for this purpose. Finally, simulations are also an effective means to train reasoning skills, metacognitive skills, risk-assessment skills, and communication skills without the overhead and complexities of real-world training.

This analysis, while highlighting the needs of team training from a naturalistic perspective, also raises research questions regarding the training effectiveness of concurrently connected VR environments like DMT:

- On what basis do trainees perceive similarity in training situations? What triggers a template in human memory? How do people seek additional information, learn from other co-trainees, or exchange data?
- How can the virtual training components be integrated with real aircraft training components to provide comprehensive training effectiveness?
- In knowledge-rich training environments, how should the knowledge be organized into virtual training modules so it fosters ready access to information when necessary?
- How can the quality of training in virtual platforms be evaluated? For example, how do we know when someone becomes an expert?

These are open questions, yielding a rich research agenda.

Lessons from History

Although there have been a number of efforts involving large-scale simulation for analysis, development, and training [8], most of this early research focused on command and control systems. Recently, there has been a substantial research thrust on identifying team skills and developing techniques for training those skills [10, 11]. These works have identified several training strategies such as guided practice and cross-training that can be effectively exploited in DMT systems. However, very little of this research has been applied to designing training for the high-performance team skills typical of DMT.

The earliest virtual platform training programs involved flight simulators and concentrated mainly on training basic procedural and psychomotor skills.

The growth in computer and communication technologies provides unparalleled opportunities to **CREATE SYNTHETIC ENVIRONMENTS TO REVOLUTIONIZE TRAINING.**

By the mid-1980s, however, technology advanced to the point it was possible to interconnect simulators and conduct team training. The first example of such training was the SIMNET project in which a number of tank simulators were interconnected to provide collective training [1]. Subsequently, several studies on team-training pilots on virtual platforms have been carried out. Principal among these were networked F-15 virtual platforms studies at McDonald Aircraft Company, Multiservice Distributed Training Testbed (MDT2) [5], and the RoadRunner'98 study of networked DMT systems (see the Crane article in this section). In all these studies, a full spectrum of simulated team missions was carried out. Teams performed their normal mission planning and post-mission analyses. A qualified instructor monitored the training scenarios and provided additional guidance to the teams.

Training effectiveness research data collected from these experiments examined both process and product measures. Process measures pertain to the frequency and quality of communication, mutual support, and decision making. Product measures pertain to numerical assessments of performance. In addition, each pilot underwent extensive interviews to determine how well they thought the training experience prepared them compared to their normal team training in their actual equipment. The results were quite positive. In all cases, the pilots showed considerable improvement on both the process and product measures from the first day of training to the last day. The probability of successfully completing a mission improved significantly during the training week. Perhaps even more encouraging were the interviews that showed participants were generally quite positive about the experience.

It is important to stress how seldom these teams are able to not only train together on a consistent basis but also be able to plan and analyze missions together. When training with actual equipment, the physical distances that separate individual players when the exercise is over make it difficult to have such sessions. As a result, even though each of the individual service teams was proficient at its part of the mission, they had very little opportunity to integrate their skills with the other members and work those skills in a realistic tactical environment. All these studies show it is possible to cross train using DMT with multiple virtual platforms in a single training package linked over distances to produce an effective composite training environment.

Naturalistic Design Considerations

The studies discussed here indicate that DMT offers the potential to be a significant training tool. Based on the data gathered thus far, and faced with the increasing pressure to reduce training costs and improve trainee skills, DMT appears to be a cost-effective training approach. Networkable, high-fidelity DMT systems encompassing a wide range of virtual training platforms are fast emerging, and are most likely to dominate the training landscape of the next millennium. However despite the current enthusiasm for DMT, a variety of significant challenges in achieving the desired training effectiveness still remain. We examine some of these issues from the point of view of human-centric and naturalistic systems design as follows.

Skill acquisition, retention, and transfer. Clearly the intent in developing DMT systems is to provide additional opportunities for individuals to acquire and maintain job-relevant skills. There is a great deal of basic research on skill acquisition and decay that can be used as a starting point for identifying those factors that influence skill acquisition and retention [9]. There is, however, very little data describing how complex skills are acquired and maintained in real-world work settings [12]. Further, almost no research involving a detailed examination of how continuation or field training experiences, as opposed to formal institutional or academic training, affects the development of a skilled team player. A well-structured plan of research is required to understand the development and retention of high-performance skills. The results of such research could then be used to define the training strategies and types of experiences necessary to maintain the training readiness of teams in general.

There is very little evidence regarding the transfer

of skills from virtual platforms to the actual equipment [2]. Although significant improvements have been repeatedly claimed using both outcome and process measures, almost no empirical evidence is available regarding the degree to which the knowledge, attitudes, and skills learned or enhanced in virtual platforms transfer to actual mission performance. This absence of transfer data is not unique to DMT. Goldstein [6] observes that very few training programs include a systematic evaluation of their effectiveness. Such evaluations are usually difficult to conduct. Bolcovici [3] describes some of the factors and the problems involved in attempting transfer of training studies within the military.

Table 4. Critical questions in developing training systems.
[illegible] the training process?
How will multiple instructors at different locations monitor and control training?
[illegible] development, modification, and [illegible]
What kind of performance feedback is required and how will it be delivered?
[illegible] needs?
How does the technical support staff (for example, network technicians) communicate critical status information to the instructors?
[illegible] initialized and monitored [illegible] performance?
How are automated performance measurement systems enabled?
[illegible] may not be readily analyzed by [illegible] (for example, communications) be used to [illegible]
When and how will mission planning and post-operative analysis be conducted?
[illegible] scenario starts?
Will the instructors be allowed to freeze and replay training events?
[illegible] and how will mission [illegible] multiple teams be conducted?
How does one ensure a "level playing field" within a homogenous virtual platform training network?

Although transfer of training research is difficult to accomplish, it is essential to validate the benefits derived from DMT. Specific studies on transfer of training from DMT systems to real-world performance are needed. Without appropriate transfer of training data, we are left in a situation similar to that encountered by many college students: one may be capable of passing the exams within a class but not be able to apply the skills and knowledge acquired in that class in other courses. In addition, transfer of training experiments provide a means of determining which variables in a virtual training system have the greatest impact on the quality of training yielded by that system. Such information is invaluable in deciding between alternative system configurations and developing the most cost-effective training systems. Finally, critical to the development and interpretation of research involving skill acquisition, retention, and transfer is the need to develop measures of individual and team performance most appropriate for the complex high-performance skills characteristic of DMT environments. Without such measures, it is difficult to develop valid training metrics, validate fidelity requirements, or determine training needs.

Instructional features. Even if it were possible to create a synthetic environment that fully replicated the real world, it is not necessarily the case that such a design would represent an optimal training environment. Indeed, if the focus is on merely re-creating reality in a digital world, it is quite possible that a suboptimal training environment is created. Such a possibility would result from failures in considering the constraints and training possibilities of hardware and software tools, and the strategies and tactics for using those tools that would allow greater training efficiencies than are currently possible in the real world.

DMT represents a quantum leap in the complexity of simulation-based training. Indeed, it involves a shift from direct control of an individual learning psychomotor and procedural skills to indirect control of large numbers of individuals executing complex hierarchically nested sequences of psychomotor, procedural, cognitive, and team skills in fluid, rapidly changing environments. This new training environment, where the instructor may be much more likely to be involved in process and supervisory control of training activities rather than one-on-one instruction, demands a human-centered design approach that targets hardware and software designs to meet user needs. Table 4 presents a set of critical design questions that must be well considered in this process.

Vertical and horizontal connectivity. Training includes actual equipment, such as aircraft, operating in its natural environment (real training events), simulation trainers operating in a virtual environment (virtual training), and computer-based training (constructive systems). These components can be combined in a number of ways to create many different synthetic environments for training that range from a level of small group engagement to strategic training involving a joint task force. It is also possible to nest various levels of training within higher levels. Thus, a small group may be engaged in a set of tasks occurring as a direct result

of the actions taken by the joint task force leader and the results of that engagement will directly influence their subsequent planning and decisions.

While it is possible to link a wide variety of live, virtual, and constructive training events both horizontally across a capability echelon and horizontally across echelons, it is essential we identify the training benefits for each level of participants in team training. The capability to create larger and larger scenarios with more participants does not necessarily increase the training value of DMT. It is possible to position individuals or teams in certain specialties or echelons serving as training aids for other specialties or echelons. If this is not considered during the design of training scenarios, we run the risk of alienating some participants and also reducing their specific task-critical training opportunities. Assuming there is a valid training reason for linking various echelons of players and classes of training in mission-specific aggregate training events, a number of unresolved technical issues (for example, aggregation and separation of team members and communication between constructive and manned systems) as well as training issues (for example, behavioral representation and scenario management) still need to be examined.

Physiological training issues. In real-life missions, team players are usually exposed to a wide variety of psychological and physiological stresses. While technology is providing us with an ever-increasing ability to replicate many of the psychological stresses, we are still severely limited in our ability to duplicate many of the physiological stressors encountered in practice. For example, consider the physiological environment in which the modern fighter pilot operates. This environment involves breathing oxygen, being cramped in a small space, experiencing a number of conflicting sensor cues, and enduring various degrees of G-stress. It is impossible to fully replicate these physiological stressors in an affordable simulator. Unfortunately, we still do not know the optimal mix of cognitive, procedural, psychomotor, and physiological training required to develop and maintain one's ability to successfully employ a fast, highly maneuverable fighter aircraft. Althought DMT may allow trainees to receive better training in certain higher-order, cognitive tasks, it may also provide poorer training in those tasks that are closely tied to one's ability to quickly recognize an opportunity and aggressively maneuver the aircraft to secure a tactical advantage. These are critical research issues that need significant attention.

Conclusion

The tremendous growth in computer and communication technologies provides unparalleled opportunities to create synthetic environments to revolutionize training. Today, we are witnessing the first attempts to integrate this technology within Air Force training systems as part of the DMT program. Initial demonstrations of DMT have been extremely encouraging. Although the DMT technologies are indeed quite impressive, they represent only a fraction of the big picture that emerges in the training landscape. Equally important are the soft technologies (human factors, education, and applied cognitive science) that are essential for the development, implementation, and assessment of training. These soft technologies are critical to the design and development of training delivery systems as well as training evaluation. While DMT has made significant technical progress, there still are a number of human-centered challenges that must be addressed in order to deliver effective and efficient training. ◼

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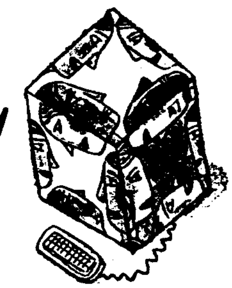
Philipp W. Peppler and
Steve Stephens

A novel technology proves ideally suited to fast-moving training environs.

IMAGE GENERATION SYSTEMS IN VIRTUAL TRAINING PLATFORMS

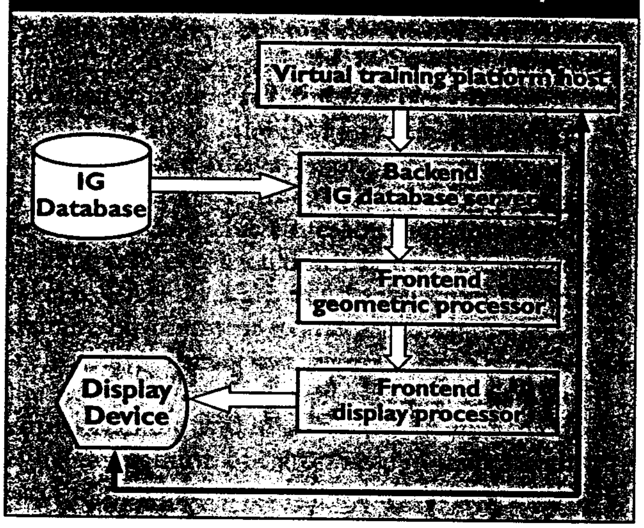


Computer-image generation in VR environments is an important component of Distributed Mission Training systems. In fact, this is one of the limiting factors of performance that is technologically challenging in most synthetic virtual training environments where visual cues play a critical role. In spite of this, computer-based training has significantly evolved by integrating computer-generated imagery at all levels of the education process. In virtual training environments, image generation systems receive positional inputs from a human or model operator, compute and display a perspective image of a 3D database on image screens, and the operators use these visual cues and references for further action. Three principal issues arise in this process: *image complexity* in terms of the size of data sets involved, *image clarity* (both desired and currently possible), and the *speed of computation and display*.

In fast-moving training environments such as flight simulators, the fields of view are usually large, change at variable rates depending on altitude and position, and require images of different levels of clarity. Comparatively, in slower environments such as automobiles and other ground-based motion devices, the fields of view are smaller, change at slower rates, and require images of high clarity. The fields of view and required clarity define the level of detail in the terrain involved, and the consequential database

ROBERT NEUBECKER

Figure 1. Conceptual architecture of IG systems.



size; the rates of change determine the computation and display speeds required. There are clear tradeoffs along these dimensions in the choice of an appropriate image-processing system besides the cost. In this article, we present the configuration of a novel *image generation* (IG) technology for fast-moving training environments developed and implemented in a DMT prototype. We also discuss some of the challenges in the next stages of evolution of this technology, and highlight critical R&D frontiers in the wide range of virtual training applications of DMT where visual systems are crucial.

An IG system is usually driven on the backend by an IG database server with frontend geometric and display processors. The backend processor is a critical determinant of overall system performance since it is responsible for maintaining very large image databases and fast information retrieval especially in high-speed training platforms. The geometric processor converts 3D database elements retrieved by the backend into 2D perspective imagery. (A conceptual architecture of an IG system is shown in Figure 1.)

The computational speed of this processor translates to the latency in image updates in the visual system of the training platform. In fast-action platforms, this speed is critical, and the technology of geometric processors has considerably improved over the last decade in this regard. The realism in virtual training platforms is directly related to this latency: the smaller the latency, the greater the realism. Hence, the quality of training is directly affected by the speed and efficiency of the database server and the geometric processor. The function of the display processor is to position, align, and integrate the final image on the display screens by mapping the output of the geometric processor into the appropriate pixels. The data output at this stage is digital, and is converted into analog signals that drive the display devices. The resolution achievable by the display processor and the end devices determine the image clarity. They should be chosen according to the requirements of a training scenario.

IG applications over the last decade have become increasingly sophisticated with multichannel image-processing capabilities. In such systems, multiple channels of image development and displays are created by adding more servers for database, geometric, and display processing. While multichannel presentations have almost become the norm in the simulator training of Air Force pilots, they are currently being used in training commercial airline pilots as well. The introduction of the additional hardware at the various stages of image processing enables multiple presentations of scenarios (for instance, at the trainee, instructor, and observer consoles), partitioning the display field into screen segments where each segment is uniquely driven by a chain of IG processors in order to lower imaging latencies in fast training platforms, and the possibility of creating 360° field of vision through multiple projections.

A Current IG Technology For Fast-Action Platforms

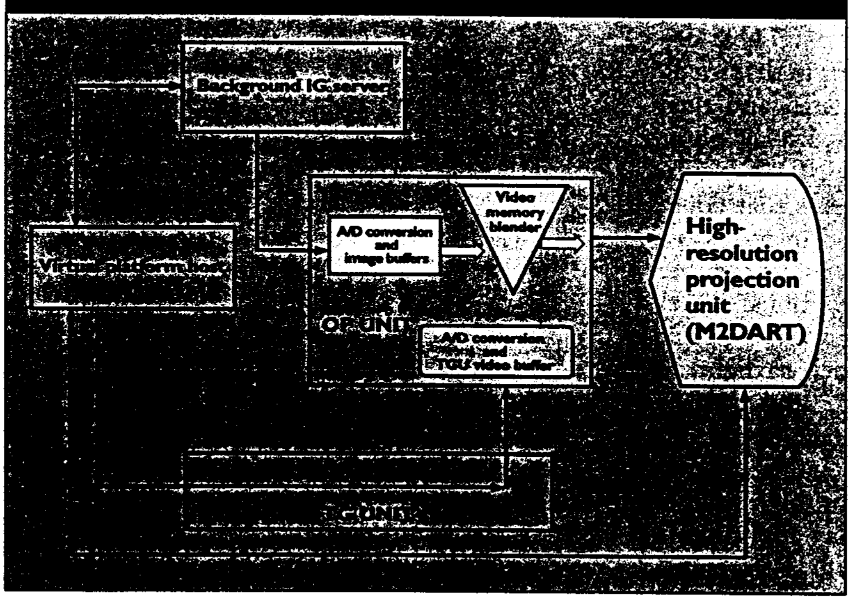
The field-of-view, brightness, and contrast of practically every visual system available today is far less than what the trainees see in the real equipment of fast-moving platforms. Most importantly, the resolution of current display systems is at least an order-of-magnitude less than that required. Because of this, current visual systems do not provide a trainee with adequate visual definition to identify other components in the field of vision in virtual platforms. For example, components such as other vehicles, roads, and bridges at realistic ranges need better visual definitions for effective training in virtual systems. Without the proper definition and realism in the visual display, many training tasks cannot be adequately performed.

To solve this problem for DMT, a three-pronged approach to developing advanced visual systems is needed. The three key areas are low-cost, deployable visual displays that encompass the training platforms and provide full-field-of-view imagery; super high-resolution display components; and rapidly generated, high-fidelity visual and sensor database systems. Current visual systems are limited by the previous generation design and business decisions. Although there is a significant effort currently under way in the IG industry to optimize all the parameters available to current display technologies, their

For DMT environments to meet any training or testing need, the IG systems must provide the visual resolution for **RECOGNIZING OBJECTS AT REALISTIC RANGES** and image refresh rates that can support the **SPEED** of fast-moving vehicular training platforms.

fundamental limitations impede their implementation into the high-end systems of the future. But new technologies are becoming available that could lead to major advancements. Taking advantage of these new technologies and applying them in innovative ways will be the key to producing high-performance visual displays of the future.

Figure 2. Architecture of microlaser IG system and M2DART.



In this regard, the Air Force Research Laboratory is spearheading the development of an IG system for fast-action training platforms. This system has been developed in conjunction with the IG industry, and implemented in the prototype virtual training platforms of the DMT system at the laboratory. The IG system is integrated with a state-of-the-art visual display system known as Mobile Modular Display for Advanced Research and Training (M2DART). A high-level architecture of this IG technology is shown in Figure 2.

The new IG system consists of a Target Generation Unit (TGU) and Overlay Processor Unit (OPU) in addition to the usual components of an IG system. The TGU and OPU provide necessary inset video and background video format conversion as well as timing synchronization. The OPU converts video from an external background IG system and TGU inset video into a format that will be displayed on the special purpose, full color, super high-resolution, microlaser-based projector system. A goal of this system is to resolve 20/20 visual acuity area-of-interest inset models at 5120 x 4096 video format. The imagery provided by this IG is viewed from the M2DART display system.

M2DART is a rear-screen, real-image, display system with eight flat projection screens integrated together to display eight channels of full-color, full-field-of-view imagery. Due to the relatively small surface area on these screens in comparison to large dome displays, the imagery is significantly brighter with much improved contrast. Our current experience with M2DART indicates it can be a cost-effective solution to many currently unfulfilled virtual platform training requirements.

Various display system manufacturers are producing their own versions of the M2DART. The modularity and flexibility of the design of the M2DART allows it to remain an excellent testbed for many important technology insertion projects such as super high-resolution projection systems, refined screen materials, and advanced image generators. Continued enhancements and upgrades to the M2DART will most likely include modifications to the display geometry such as the use of curved sur-

faces instead of the current flat-panel facets, and the development of low-cost, high-quality collimating rear projection screens. The M2DART appears to be a solid design approach from which future DMT visual displays should be based.

Challenges and Emerging Solutions

For DMT environments to meet any training or testing need, the IG systems must provide the visual resolution for recognizing objects at realistic ranges and image refresh rates that can support the speed of fast-moving vehicular training platforms. An analysis of M2DART system reveals that achieving this level of acuity requires a projector system capable of projecting 5120 x 4096 pixels. At a minimum, to produce high-quality dynamic images, the image generation update rate and the display refresh rate must both be 60 Hz, noninterlaced. This represents an order-of-magnitude increase over what is considered high-resolution projection technology. Clearly, a CRT-based projector system could not provide this level of resolution.

An alternate emerging technology for providing such resolution is laser-based projection. These displays are known as direct-write systems in that small, solid-state, eye-safe lasers are modulated and then scanned directly onto a screen. No display phosphors or LCD elements are involved. Early prototypes have demonstrated many benefits that could substantially improve DMT visual displays. Most importantly, laser-based displays can achieve the spot size required for very high resolutions. Other benefits include improved display contrast, excellent display brightness (that could approach daylight), a significantly improved color gamut, and a large depth of focus. Newly developed red, green, and blue solid-state laser sources, each operating at a primary color, provide the most efficient, high-brightness projection light source for display applications to date. The combination of solid-state lasers, parallel-scan architectures, and new high-speed spatial light modulators that modulate the video into the laser beams, make a 5120 x 4096, 60 Hz, noninterlaced projector possible. This projection technology also shows promise for developing lightweight, high-resolution helmet-mounted displays in mobile, virtual task-training platforms.

Other new technologies, such as commercial PC-based graphics, could be used to improve IG capability and at the same time drive down cost. PC-based 3D graphics have made significant strides and now accelerate many aspects of graphical visualization. Competition is driving advancements at a rapid rate. In some cases, the graphics capabilities of PC-driven systems are nearly doubling every six months. While these are some of the current solutions, the real challenge is to capitalize on these new technologies and develop super high-resolution visual system components that include super high-resolution projectors (5120 x 4096, 60 Hz, noninterlaced video), lightweight high-resolution displays, and the associated image generators with parallel, high-speed digital interfaces.

Conclusion

DMT is a demanding virtual training environment that requiring advanced levels of IG and display technology are still developing. Major advances in the capabilities of visual systems such as resolution, contrast, and brightness need to be achieved. Development of IG databases in any team-training scenario is time-consuming. However, the silver lining is that new technologies are rapidly emerging to produce giant leaps in these directions. While microlaser systems are revolutionizing the high-end IG systems, commercial PC-based graphics will soon accelerate DMT visual systems with greatly reduced costs. ■

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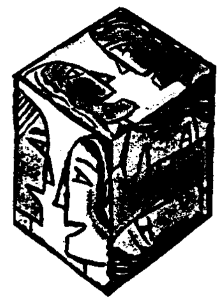
Peter Crane

An experimental training program tests the DMT mettle through some tough terrain.

IMPLEMENTING DISTRIBUTED MISSION TRAINING

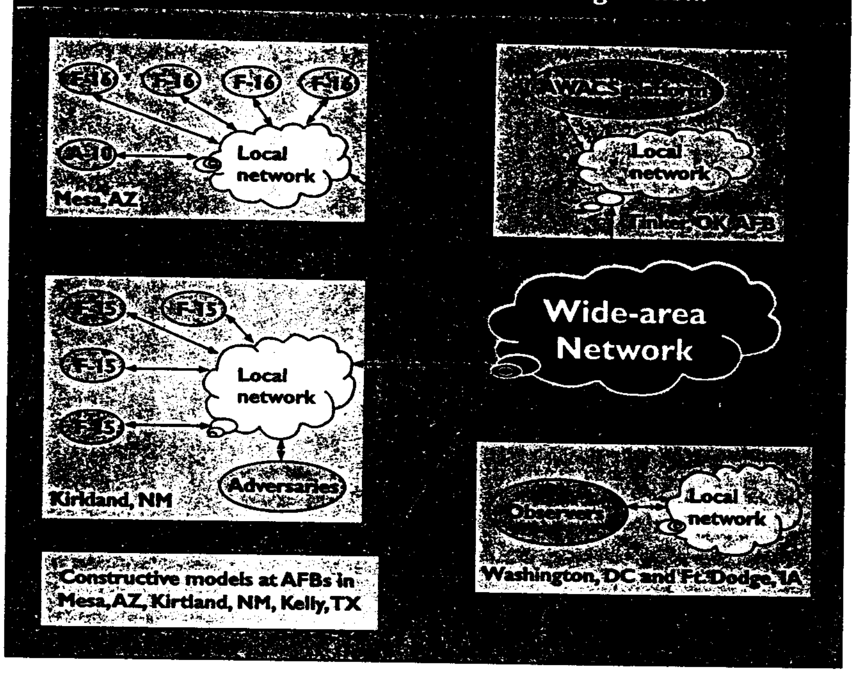


The goal of Distributed Mission Training is to provide individuals with opportunities to train for real-world operational missions in an environment that is not constrained by security, cost, and safety restrictions. Even the most elaborate real-world field exercises place severe limitations on participants so they cannot really train the way they will operate. Unlike a training range, pilots in a virtual flight training environment can fly, attack, and defend themselves as they would in wartime. More importantly, they can then review their actions, discuss what they did well or poorly during training, decide how they would do it differently in the future, and then practice new plans in subsequent training events.

Here, we present a case analysis of a DMT implementation. An experimental training program named RoadRunner'98 was conducted at the U.S. Air Force Research Laboratory to evaluate the training effectiveness of DMT systems. RoadRunner'98 combined virtual (man-in-the-loop) training events on DMT platforms with computer-generated constructive models. The systems were integrated over a wide geographic area through secure networks carrying voice, data, and image information.

The objectives of RoadRunner'98 were to demonstrate the state-of-the-art DMT technologies, identify the strengths and shortfalls of these

Figure 1. Roadrunner'98 DMT configuration.



technologies, explore how to best use this new training environment to enhance team training and develop a research and development agenda for the future.

DMT Structure of Roadrunner'98

RoadRunner'98 consisted of four F-16, one A-10, four F-15, and AWACS command and control virtual simulators networked both locally and over a wide area as shown in Figure 1. In addition, limited fidelity platforms were linked as adversaries, and an observation capability was provided at the Pentagon. The composite force missions were carried out over a virtual gaming area. Each mission was executed over a secure, wide-area network using Distributed Interactive Simulation (DIS) communications protocols. In these missions, virtual platform players interacted with constructive forces including friendly and enemy fighters, helicopters, and ground vehicles, plus enemy surface-to-air threats.

All links in the network were commercial T-1 lines except for the connection from Kirtland Air Force Base, NM, to Tinker Air Force Base, OK, which was built around two conventional telephone lines, and the connection from Mesa to Ft. Dodge was an experimental satellite link. The bandwidth provided by the T-1 line was fully sufficient for the exercises conducted. However, phone line connections to Tinker provided significantly less bandwidth. Therefore, the data stream was filtered down to only voice communication and aircraft location. While this bandwidth was sufficient to support virtual AWACS participation, the connection suffered from reliability problems.

All training platforms were virtual. The virtual F-16 platforms were equipped with the Modular-Mobile Display for Advanced Research and Training (M2DART)—a state-of-the-art, full-field view, rear-projection, dome-display system. The visual imagery was provided to two of the F-16 platforms from Lockheed-Martin SE2000+ computer image generators, which utilized polygonized terrain and feature representations augmented with cell texture maps. Imagery was provided to the other platforms from Silicon Graphics' Reality Monster image generators which used polygonized terrain representations augmented with aerial mapping photographs of the training area. Compared to the Reality Monsters, the SE2000+ image generators provide more vertical features that can be discerned at low altitude, while the Reality Monsters provided more scene realism at medium altitudes. The four virtual F-15 platforms were equipped with a single 48-inch CRT displaying each forward, out-the-window visual imagery. The AWACS controllers used a training simulator adapted for DMT exercises.

Constructive simulations provided many active entities, including AWACS and tanker aircraft, and supporting friendly combat forces. Constructive forces also included enemy fighter aircraft and a surface-to-air defense system that incorporate radar, missiles, and anti-aircraft artillery. The control consoles at the various sites provided both an interface for system operators to conduct a mission and an observation station for instructors to monitor team performance. The control console incorporated an operator's station, the test director's station, and an observer's station. The instructor monitored mission progress on a six-screen video display system. The test director could communicate with all participants and issue global operational commands. The post-mission analysis systems incorporated synchronized replay of a plan-view display together with videotapes recorded from each virtual training platform.

Training Scenarios

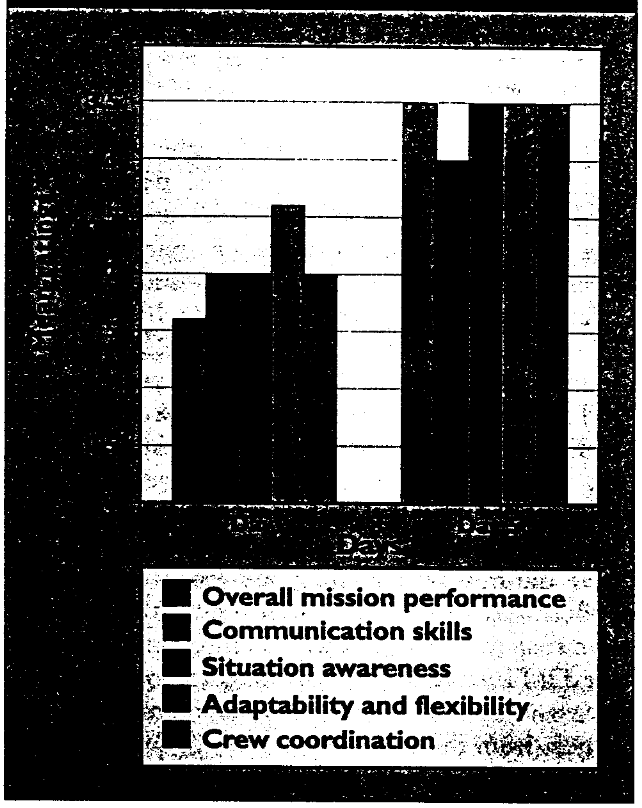
The training scenarios were based on team exercise objectives, technical feasibility, and similarity to F-16 and F-15 operational missions. The training scenarios were designed to simulate a small portion

RoadRunner'98 and similar exercises provide information that will **SIGNIFICANTLY AFFECT** the development of DMT systems and applications.

of an ongoing conflict that included both ground and air forces. In these scenarios, F-16s would typically fly into enemy controlled territory to attack a target such as an airfield defended by both surface and airborne threats with air cover from the F-15s. The exercises were conducted over a synthetic gaming area in Nevada. Pilots were free to fly anywhere within the gaming area, at any altitude, and at any speed. Pilots were also free to employ countermeasures against missiles as required. The mission scenarios required pilots to fly specified routes to and from the target areas, which were selected to insure pilots would encounter constructive forces. If attacked, however, pilots were free to deviate from planned routes. The role of the virtual F-15s was to achieve air superiority within a specified time interval. The role of the virtual F-16s was air-to-surface attack, and the task of the AWACS team was to provide radar coverage. The lead F-16 pilot was the mission commander whose tasks were to organize and instruct the different virtual teams on the mission plan, lead and coordinate their actions, and conduct post-mission discussions.

Three sets of pilots and AWACS crews with 300–1,200 actual flying hours to their credit participated in the study. At the beginning of each mission-planning period, the mission leader contacted the other players to review the mission plan. At the scheduled time, pilots and controllers would get into their platforms and perform systems and communication checks. When all players had checked in, the test director commenced the training exercises. After each scenario was completed, teams were instructed to conduct their post-mission analyses in two phases: local (intrateam) and wide-area (interteam). During local analysis, teams would replay the mission tapes with the goal of understanding what happened during the mission and generating points for review by all participants. The teams prepared a list of discussion topics for the mission commander who prepared the interteam discussion agenda. All teams would then restart their tapes at the beginning of the mission and pause for discussion as directed by the mission commander. At the conclusion, the participants filled out a questionnaire identifying performance issues of DMT.

Figure 2. Instructor ratings for test missions.



Results and Mission Performance

RoadRunner'98 was conducted over a period of five days, with each team performing two training missions per day. In order to evaluate the training effectiveness of DMT, similar missions were performed on the first and last days of training. This exercise structure enabled an assessment of team performance changes attributable to the DMT experience in the five days of training.

All missions were completed with no aborts or significant delays. The exercises established the reliability of the communication systems and the sufficiency of the bandwidth provided for the scenarios tested. Comparing team performance from the first mission to the last shows that accuracy in ordnance delivery increased by 30% and aircraft losses to enemy fighters decreased by 44%.

In addition to mission performance data, training instructors observing from the test director's console rated their team using a (1–5) teamwork effectiveness scale. Instructor ratings significantly improved for overall mission performance, communications and coordination, situation awareness, and crew coordination from the first day to the last day of training as shown in Figure 2.

Assessments of the quality of DMT were carried out by the trainees as well. Before the start of the RoadRunner'98 program, they were asked how well their current level of training on actual aircraft prepared them for many of the mission tasks. They completed a similar questionnaire at the end of the week regarding the effectiveness of DMT for the same tasks. Aircraft training was rated higher than DMT primarily for tasks involving visual detection and recognition of aircraft in their fields of view. DMT was rated as more effective than aircraft training for tasks infrequently practiced in the air due to resource, safety, and security considerations. In particular, DMT was rated as more effective for radar and communications intensive, beyond-visual-range tasks.

Pilots were also asked to critique the effectiveness of DMT after each mission. The weak points were the inability to determine another player's aspects at realistic ranges and the behaviors of some of the constructive models. The consistent strengths of DMT were the mission recording and replay systems, the opportunities for premission planning and post-mission analyses, the high level of immersion provided by the DMT environment compared to other simulators, and the instructor's ability to monitor all team players from the console.

Summary and Conclusions

RoadRunner'98 and similar exercises provide information that will significantly impact the development of DMT systems and applications. Don Norman [1], in his work on product development, describes how systems designs based on lists of desired features often fail when they are integrated into work environments. He recommends that designs should emerge from observing people at work along with frequent prototype evaluations by users and the design team.

Reviewing participant critiques from RoadRunner'98 demonstrates the value of Norman's advice. Everyone who has flown an F-16/M2DART simulator, other than fighter pilots, rates its fidelity and training potential as unlimited. While the pilots in RoadRunner'98 appreciated the scene quality, they also criticized simulators for failing to display other aircraft adequately. As configured during RoadRunner'98, the F-16/M2DART did not support the intended user's needs although non-pilots would never have identified this shortcoming. On the other hand, AFRL's mission replay system, which was a conglomeration of a DIS plan-view display and four videotapes, appears awkward and clumsy to any engineer. While pilots recognized its flaws, they rated its training value extremely high. Teams would frequently spend two hours reviewing a 45-minute mission and still be talking about it as they left the debriefing room. During RoadRunner'98, the replay system was neither graceful nor elegant, but it was highly effective in providing the pilots with the information they needed.

The objective of RoadRunner'98 was to evaluate the quality of virtual team training provided with state-of-the-art VR and networking technologies and to evaluate their potential for significantly enhanced training capabilities. Overall, the participants and training instructors rated DMT as very effective within specified domains, notably, multiaircraft air combat against multiple enemy fighters. The most significant opportunities for improvement in DMT technologies were in visual displays, constructive modeling, simulation of electronic interactions, and systems for distributed mission planning and post-mission analysis.

Another major application of DMT identified by the participants and instructors is to use these technologies to gain leadership skills and experience. The team leader plans the mission, makes decisions, informs the other players, manages the missions, and leads the post-mission analyses. Gaining this experience in actual aircraft or other equipment can be very expensive. The participating players in RoadRunner'98 used the exercise to provide leadership experience for younger individuals at greatly reduced cost compared to aircraft training. Overall, RoadRunner'98 demonstrated both the value and limitations of DMT and also illustrated the areas for improvement in future DMT systems. ◼

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